Multi-step VLBI observations of weak extragalactic radio sources to align the ICRF and the future Gaia frame

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MULTI-STEP VLBI OBSERVATIONS OF WEAK EXTRAGALACTIC RADIO SOURCES TO ALIGN THE ICRF AND THE FUTURE GAIA FRAME

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Abstract. The space astrometry mission Gaia will construct a dense optical QSO-based celestial reference frame. For consistency between optical and radio positions, it will be important to align the Gaia frame and the International Celestial Reference Frame (ICRF) with the highest accuracy. Currently, it is found that only 10% of the ICRF sources (70 sources) are suitable to establish this link, either because they are not bright enough at optical wavelengths or because they have significant extended radio emission which precludes reaching the highest astrometric accuracy. In order to improve the situation, we have initiated a VLBI survey dedicated to finding additional suitable radio sources for aligning the two frames. The sample consists of about 450 sources, typically 20 times weaker than the current ICRF sources, which have been selected by cross-correlating optical and radio catalogues. This paper presents the observing strategy to detect, image, and measure accurate positions for these sources. It also provides results about the VLBI detectability of the sources, as derived from initial observations with the European VLBI Network in June and October 2007. Based on these observations, an excellent detection rate of 89% is found, which is very promising for the continuation of this project.

1 Context

The International Celestial Reference Frame (ICRF) is the realization at radio wavelengths of the International Celestial Reference System (ICRS; Arias et al. 1995), through Very Long Baseline Interferometry (VLBI) measurements of extragalactic radio source positions (Ma et al. 1998; Fey et al. 2004). It was adopted by the International Astronomical Union (IAU) as the fundamental celestial reference frame during the IAU 23^{rd} General Assembly at Kyoto, in 1997. The ICRF currently consists of a catalogue with the VLBI coordinates of 717 extragalactic radio sources (from which 212 are defining sources), with sub-milliarcsecond accuracy.

The European space astrometry mission Gaia, to be launched by 2011, will survey about (i) one billion stars in our Galaxy and throughout the Local Group, and (ii) 500 000 Quasi Stellar Objects (QSOs), down to an apparent optical magnitude V of 20 (Perryman et al. 2001). Optical positions with Gaia will be determined with an unprecedented accuracy, ranging from a few tens of microarcseconds (μas) at magnitude 15–18 to about 200 μas at magnitude 20. Unlike Hipparcos, Gaia will permit the realization of the extragalactic reference frame directly at optical bands, based on the QSOs that have the most accurate positions (i.e. those with $V \leq 18$ (Mignard 2003); it is expected to detect at least 10 000 of such QSOs (Mignard 2002)). A preliminary Gaia catalogue is expected to be available by 2015 with the final version released by 2020.

In the future, aligning the ICRF and the Gaia frame will be crucial for ensuring consistency between the measured radio and optical positions. This alignment, to be determined with the highest accuracy, requires several hundreds of common sources, with a uniform sky coverage and very accurate radio and optical positions. Obtaining such accurate positions implies that the link sources must have (i) an apparent optical magnitude V brighter than 18 (for the highest Gaia astrometric accuracy), and (ii) no extended VLBI structures (for the highest VLBI astrometric accuracy). In a previous study, we investigated the current status of this alignment based on the present list of ICRF sources (Bourda et al. 2008). We showed that although about 30% of the ICRF sources have an optical counterpart with $V \leq 18$, only one third of these are compact enough on VLBI

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scales for the highest astrometric accuracy. Overall only 10% of the current ICRF sources (70 sources) are available today for the alignment with the future Gaia frame. This highlights the need to identify additional suitable radio sources, which is the purpose of the project described here.

2 Strategy to identify new VLBI radio sources for the ICRF–Gaia alignment

Searching for additional radio sources suitable for aligning accurately the ICRF and the Gaia frame could rely on the VLBA Calibrator Survey (VCS; Petrov et al. 2008 and references therein), a catalogue of more than 3000 extragalactic radio sources observed with the VLBA (Very Long Baseline Array). This investigation is currently underway. Another possibility is to search for new VLBI sources, which implies going to weaker radio sources that have a flux density typically below 100 mJy. This can now be envisioned owing to the recent increase in the VLBI network sensitivity (i.e. recording now possible at 1Gb/s) and by using a network with big antennas like the EVN (European VLBI Network). A sample of about 450 radio sources that mostly have never been observed with VLBI (i.e. not part of the ICRF or VCS) has been selected for this purpose by cross-identifying the NRAO VLA Sky Survey (NVSS; Condon et al. 1998), a deep radio survey (complete to the 2.5 mJy level) that covers the entire sky north of $-40°$, with the Véron-Cetty & Véron (2006) optical catalogue of QSOs. This sample is based on the following criteria: $V \leq 18$ (for an accurate position with Gaia), $\delta \geq -10°$ (for possible observing with northern VLBI arrays), and NVSS flux density $\geq$ 20 mJy (for possible VLBI detection). The observing strategy to identify the appropriate link sources in the sample includes three successive steps: (1) to determine the VLBI detectability of these weak radio sources, mostly not observed before with VLBI; (2) to image the sources detected in the previous step, in order to reveal their VLBI structure; and (3) to determine an accurate astrometric position for the most point–like sources of the sample.

3 VLBI results

Initial VLBI observations for this project were carried out in June and October 2007 (during two 48–hours experiments), with a network of 4 or 5 VLBI antennas from the EVN. The purpose of these two experiments was to determine the VLBI detectability of the 447 weak radio sources in our sample based on snapshot observations. Our results indicate excellent detection rates of 97% at X band and 89% at S band. Overall, 398 sources were detected at both frequencies. The overall mean correlated flux densities were determined for each source and band by the mean over all scans and baselines detected. At X band, 432 sources were detected and the mean correlated fluxes range from 1 mJy to 190 mJy, with a median value of 26 mJy. At S band, 399 sources were detected and the mean correlated fluxes range from 8 mJy to 481 mJy, with a median value of 46 mJy. A comparison between the X-band flux density distribution for our sources, those from the VCS and the ICRF shows that the sources of our sample are indeed much weaker. On average, they are 27 times weaker than the ICRF sources and 8 times weaker than the VCS sources. The spectral index α ($S \propto \nu^{\alpha}$, S being the source flux density and ν the frequency) was determined for the 398 radio sources detected at both frequencies; the sources with a compact core are expected to have $\alpha > -0.5$. The median value of α in our sample is -0.34 and about 70% of the sources have $\alpha > -0.5$, hence indicating that they must have a dominating core component, which is very promising for the future stages of this project. The next step will be targeted at imaging the 398 sources that we have detected at both frequencies, by using the global VLBI network (EVN+VLBA), in order to identify the most point–like sources and therefore the most suitable ones for the ICRF–Gaia link.

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